RESULTS OF ELECTROCORE™ PILOT TESTING AT E.C. GASTON STEAM PLANT

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ABSTRACT

The ElectroCore is a new particulate control technology which is intended to augment the performance of aging or underperforming ESPs. Unlike conventional electrostatic precipitators which collect particles on their surfaces, the ElectroCore acts as a separator thereby allowing it to overcome many of the common reentrainment problems. A pilot-scale Advanced ElectroCore Field Prototype was installed at Alabama Power Company's E.C. Gaston Unit #4 to evaluate its performance when located downstream of a utility ESP. The unit was designed to process a slipstream with a nominal flow rate of 6,000 acfm and a specific separating area (SSA) of about 100 ft^2 per thousand acfm. The unit was built under a contract from DOE (DE-FC26-00NT40757) and received additional testing support under EPRI contract (EP-P4245/C2075). The U.S. EPA also provided testing support in conjunction with mercury removal performance. In addition, Southern Company Services, Inc. along with its affiliate, Alabama Power Company provided a host site and technical services to support this test effort. The Advanced ElectroCore Field Prototype was tested for particulate and mercury removal performance from November 2001 through February 2002. This paper discusses the performance of the ElectroCore and its ability to control PM and mercury.

INTRODUCTION

The ElectroCore is a retrofit technology designed to be installed downstream of an under-performing electrostatic precipitators (ESPs). The ElectroCore consists of an array of cylindrical separators with a tangential inlet, a tangential outlet and two axial outlets as shown schematically in Figure 1. The incoming particles are precharged in a temperature controlled precharger and enter the separators along their outer wall. A large-diameter electrode, placed along the separator's central axis, is given an electric charge of the same polarity as the particles to create at electric field that induces a radially outward electrical force on the charged particles. The combined electrical and centrifugal forces cause the particles to remain in the near-wall region where they are extracted with the bleed flow from the tangential outlet slot. The clean flow is extracted axially from the ends of the separators. The bleed flow, which is about 10 percent of the clean flow, is directed either back to the inlet of the upstream ESP or to a separate collector. These arrangements are shown schematically in Figure 2 and Figure 3.

The separators operate in a continuous mode without collecting particles so no rapping is required. There are no hoppers so sneakage is eliminated. The central electrode operates without corona so back corona is eliminated in the separators. Back corona in the precharger is eliminated by cooling the ash layer on the grounded electrode thereby reducing the ash temperature and electrical resistivity.

The work described here is a follow on from the testing done with a single ElectroCore separator tested at Alabama Power Company's Plant Miller in May and June of 1997[1]. This work was conducted to determine how effectively a larger scale ElectroCore could remove particulate matter and mercury from the exhaust gas from a coal fired power plant.

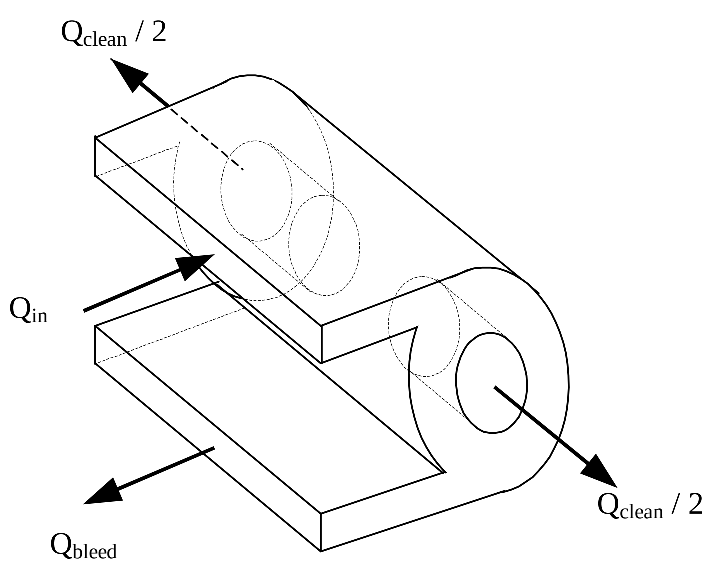

Figure 1: Schematic of a Single Cylindrical Separator.

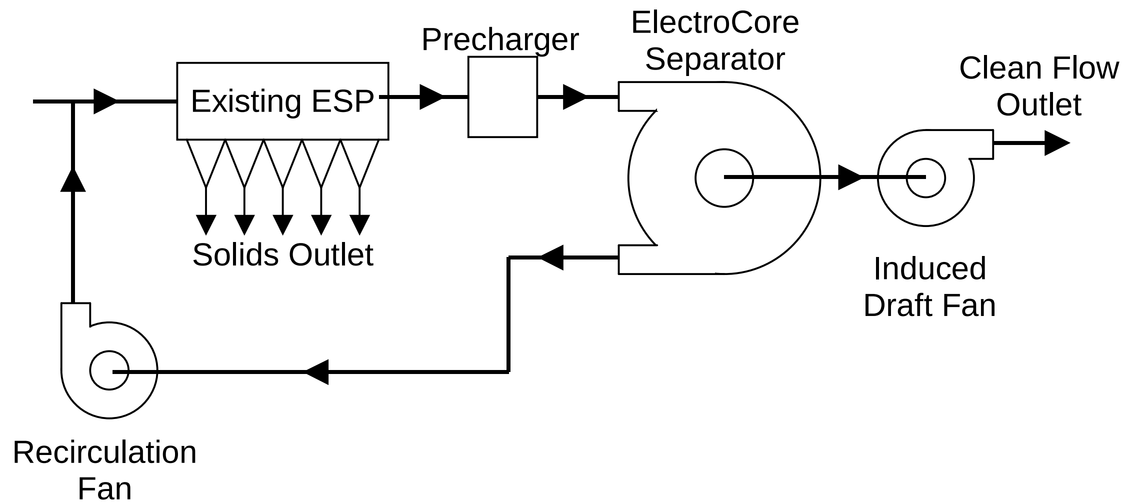

Figure 2: ElectroCore Configuration With Bleed Flow Directed Back to ESP Inlet.

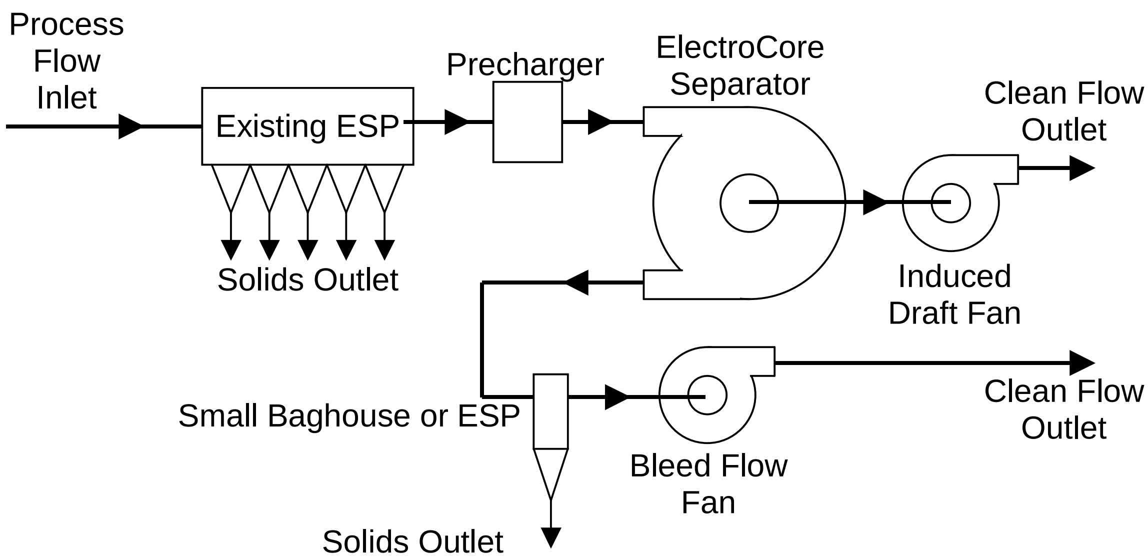

Figure 3: ElectroCore Configuration With Bleed Flow Directed to Separate Collector.

EXPERIMENTAL

The system tested at Alabama Power Company's E.C. Gaston Steam Plant is shown schematically in Figure 4. The system consisted of a dry scrubber, that was used to test sorbents for capturing mercury, a precharger, an Advanced ElectroCore module containing 12 ElectroCore separators, fans and connecting ductwork.

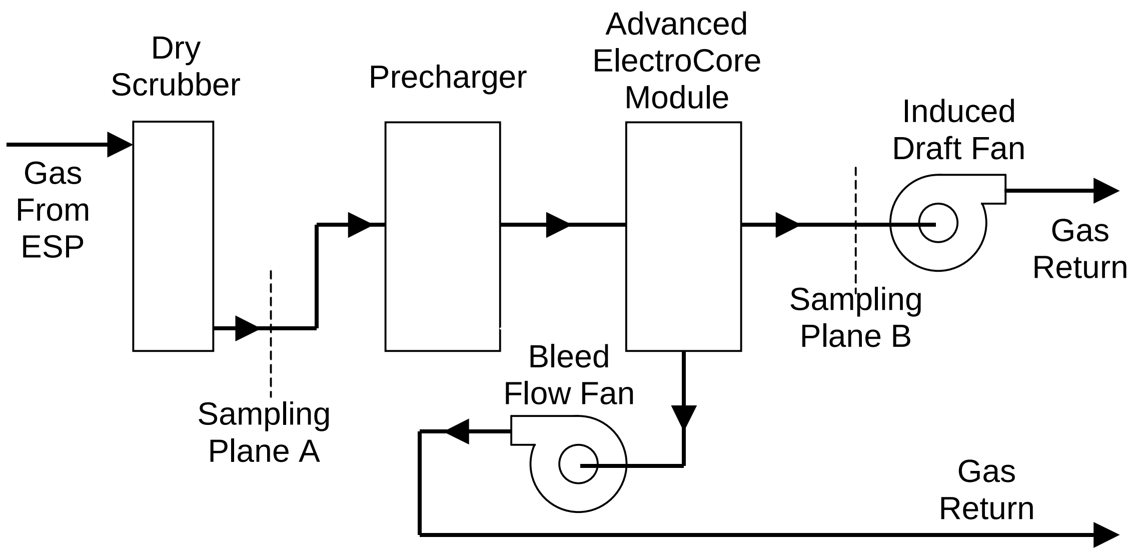

Figure 4: Advanced ElectroCore Field Prototype Configuration.

The precharger is a temperature controlled electrode type developed by EPRI in the 1980s[2]. The precharger contains 8 discharge electrodes 3.2 mm (1/8 inch) in diameter and 12 grounded electrodes 60 mm (2.375 inch) diameter. The grounded electrodes have forced circulating water at about 40.5°C (105°F) flowing through them to cool the layer of dust that forms on their outer surface. Cooling the dust layer reduces its electrical resistivity thereby allowing higher current densities than otherwise could be obtained without cooling. The temperature controlled electrodes allow a relatively small precharger to effectively charge high resistivity dust particles.

Figure 5 shows the precharger (unit on the right) being installed at E.C. Gaston Steam Plant. Figure 6 shows the internals of the precharger as viewed from the hopper looking upward. The gas flow is from left to right. The large diameter pipes are the grounded electrodes and the wires between them (top to bottom) are the discharge electrodes.

The Advanced ElectroCore module assembly is shown in Figure 7. The module contains two tiers of six separators each. On each tier there are three left hand and three right hand separators with the inlet running down the center space. The inlets to the upper and lower tiers are shown on the left side of the module in Figure 7.

Figure 5: Precharger - External View.

Figure 6: Precharger Internals – Looking Up From Bottom.

Figure 7: Advanced ElectroCore Module Assembly.

The particulate removal efficiency tests were conducted by sampling the particulate concentrations entering the system at Test Plane A and sampling the particulate concentration in the clean flow outlet stream at Test Plane B. The locations of these test planes are shown in Figure 4. The inlet and outlets were simultaneously sampled using EPA Method 5. Tests were conducted at various flow rates and separator electrode applied voltages.

For the mercury tests, the inlet test plane was moved to the inlet of the dry scrubber and sorbent was injected into the top of the scrubber. The average rate of sorbent injection was calculated from the injection time and change in weight from the injector. The concentration of mercury in the gas stream was determined by taking simultaneous inlet and outlet samples using the Ontario Hydro method.

RESULTS AND DISCUSSION

The analysis of the EPA Method 5 data shows two trends. The first is that the ElectroCore outlet particulate concentration and efficiency are a strong function of inlet particulate concentration. The second is that the best performance tests occurred during the runs to evaluate the effect of separator electrode voltage on separator performance. The results are shown in Figure 8. The outlet particulate concentration has been plotted against the inlet concentration, which was an uncontrollable variable. Next to each data point is listed the voltage applied to the separator electrode, the bleed flow ratio and the gas residence time in seconds. The bleed flow ratio, ß, is defined as the flow rate of gas exiting through the tangential outlet slots to the flow rate of gas entering the separator inlets. The nominal bleed flow ratio is 10 percent. That is, of the gas entering the separators, 90 percent will exit axially out the end of the separators while 10 percent will be directed to a particle collector. The base case gas residence time was 1.8 seconds based on a specific separating area (SSA) of 100 ft^2/kacfm and a 10 percent bleed flow ratio. Test points with a 3.6 second residence time correspond to an SSA of 200 ft^2/kacfm.

The general trend of increasing outlet particle concentration with increasing inlet particle concentration is apparent in Figure 8. Trend lines have a lower slope that the constant efficiency curves indicating that as the inlet particle concentration increases, the ElectroCore efficiency increases as well. This is a tendency also observed in electrostatic precipitators (ESPs) and can be attributed to the increasing importance of space charge to the electric field strength in the separator.

When operating with no voltage applied to the central electrode, the separators rely only on centrifugal forces and on the electric field due to the space charge to perform the gas/particle separation. The five data points with no applied voltage and varying residence times show that there is no improvement in performance with increasing gas residence time. In ESPs, increasing residence time generally decreases outlet loading. In the ElectroCore, increasing residence time results in a reduction in inlet velocity and therefore, a reduction the centrifugal forces acting on the particles. A doubling of gas residence time reduces centrifugal forces acting on particles by 75 percent. The data suggest that the improvement in performance expected from the analysis of electrical forces acting on the particles may be offset by the reduction in centrifugal forces.

Perhaps the most interesting observation about the data was that, the ElectroCore performance with no applied voltage to the separator electrode was comparable to the performance when the maximum voltage was applied, but the performance improved when a “moderate” voltage was applied. Typically, spark over occurred at about –60 kV so the points with –60 kV and –55 kV are maximum voltage points. The reason why the performance should initially improve with increasing separator electrode voltage and then degrade can be understood by looking at the electrical forces acting on particles that contact the inner wall of the separator. The electrostatic force can be estimated using Equation 1.

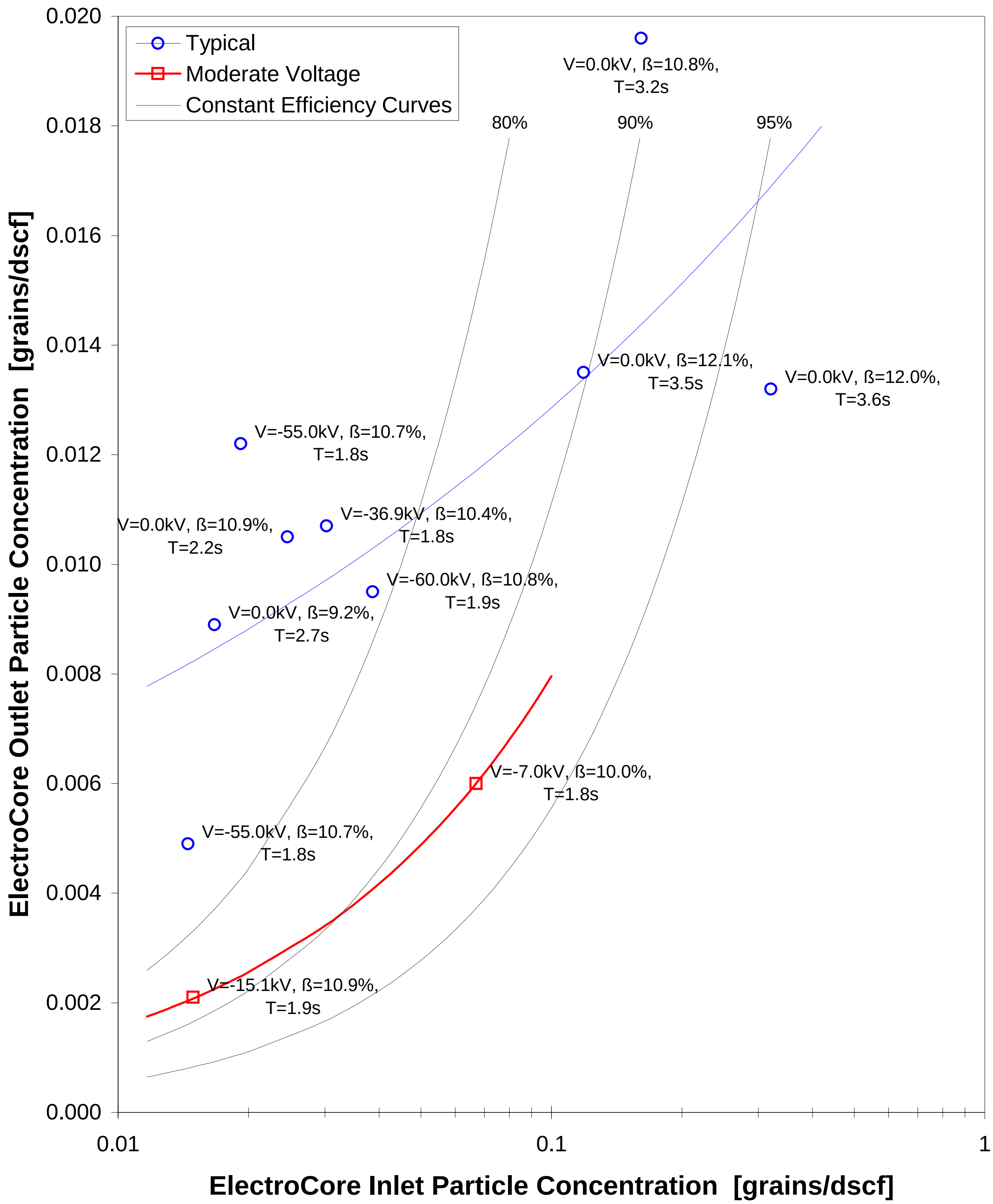

Figure 8: Advanced ElectroCore Inlet and Outlet Particle Concentrations.

$$f = \frac{1}{2}\ \varepsilon_o \left[\left(\frac{j\rho\varepsilon_1}{\varepsilon_o} \right)^2 - \left(\frac{V - (\mathrm{R}_2 - t) j\ \rho\ \mathrm{Ln}\left(\frac{\mathrm{R}_2}{\mathrm{R}_2 - t} \right)}{(\mathrm{R}_2 - t)\,\mathrm{Ln}\left(\frac{\mathrm{R}_2 - t}{\mathrm{R}_1} \right)} \right)^2 \right] \qquad \text{Equation 1}$$

Where:

f	Force per unit area holding dust layer to inside of separator wall
ε_o	Permittivity of free space
j	Current density at the gas to dust layer interface
ρ	Dust resistivity
ε_1	Permittivity of dust layer
V	Voltage on separator central electrode
t	Thickness of dust layer
R_1	Central electrode radius
R_2	Radius of inner wall of separator

Equation 1 is the electrical clamping force equation from Oglesby and Nichols[3] derived in a cylindrical coordinate system rather than in rectangular coordinates. In the ElectroCore separators, the coating of dust on the wall is very thin so if one assumes $t << R_2$ then Equation 1 simplifies to

$$f = \frac{1}{2}\ \varepsilon_o \left[\left(\frac{j\rho\varepsilon_1}{\varepsilon_o} \right)^2 - \left(\frac{V}{\mathrm{R}_2\ \mathrm{Ln}\left(\frac{\mathrm{R}_2}{\mathrm{R}_1} \right)} \right)^2 \right] \qquad \text{Equation 2}$$

The term

$$\frac{j\rho\varepsilon_1}{\varepsilon_o} \qquad \text{Equation 3}$$

is the electric field strength in just inside the dust layer at the gas/dust interface and is controlled by the current passing through the dust layer. The term

$$\frac{V}{\mathrm{R}_2\ \mathrm{Ln}\left(\frac{\mathrm{R}_2}{\mathrm{R}_1} \right)} \qquad \text{Equation 4}$$

is the electric field strength in the gas just outside the dust layer and is controlled by the voltage applied to the central electrode. In general, the electric field strength just inside the dust layer is different than the field strength just outside the dust layer. From Gauses' law, this step-like jump in the field strength must be accompanied by a surface charge that appears at the dust/gas interface. The force per unit area at the dust/gas interface is the product of the surface charge density and the average field strength there. If the field strength in the dust layer is greater than in the gas, the resulting surface charge will produce in a force acting to hold the dust layer to the wall. When the field strength in the dust layer is lower than in the gas, the force acts to propel the dust back into the bulk flow.

In the ElectroCore, there is no corona current in the separators. The only current comes from the charged particles and gas ions coming out of the precharger. With the small current density in the separator, it is easy to envision how high voltage on the central electrode can induce particles to be propelled into the bulk flow and be lost to the clean flow resulting in higher than expected outlet emission rates.

The foregoing analysis suggests that there may be an optimum voltage at which to operate the separator central electrode. From Equation 2, the optimum voltage should increase with increasing inlet loading and with increasing dust resistivity. The higher the optimum voltage, the higher should be the separation efficiency so the ElectroCore separators may operate best with high resistivity ash. If the separator module were connected to ground through an ammeter then the current density could be determined real-time and the electrode voltage adjusted accordingly. A secondary input from a P5A or similar in-duct opacity measuring device could further enhance the real-time performance of an ElectroCore system by further tuning the separator voltage to minimize the outlet loading.

In Figure 9 the results have been expressed in terms of emission rates in pounds per million Btu. The results have been converted by using a dry oxygen-based F factor of 10,000 dscf per million Btu and an oxygen mole fraction of 8 percent on a dry basis. Figure 9 shows that the lowest emission rate was below 0.005 lb_m/million Btu and that an ElectroCore could achieve a 0.03 lb_m/million Btu for systems currently operating at about 0.4 lb_m/million Btu or lower. That range may be increased if the separator voltage can be truly optimized.

As a point for comparison, the single ElectroCore separator tested at Plant Miller in 1997 achieved a minimum outlet particle concentration of 0.0064 grains/dscf with an inlet concentration of 0.056 grains/dscf. Comparing this to the results shown in Figure 8, the performance of the Advanced ElectroCore operated with moderate separator voltages performance is slightly better than the performance of the single separator. This improvement comes along with fact that the Advanced ElectroCore module processes 12 times the flow of the original separator.

At the time of this writing the mercury capture results from the Ontario Hydro tests were unavailable. However, preliminary results from a mercury monitor provide by EPA suggest that the total mercury removal was on the order of 90 percent at an activated carbon injection rate of 7 lb/million cubic feet of gas. The test program did not provide an opportunity to optimize sorbent utilization through recirculation of unspent sorbent.

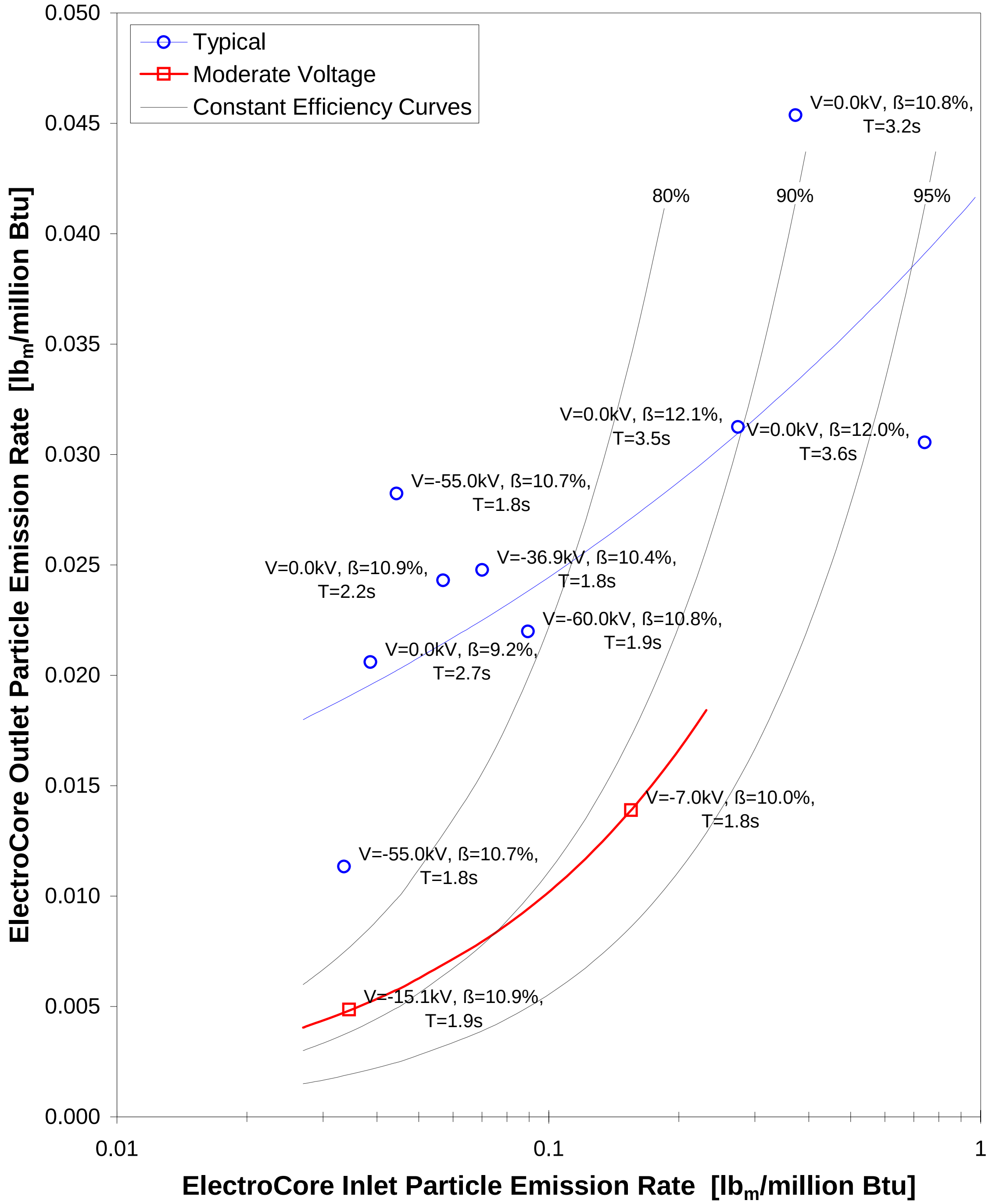

Figure 9: Advanced ElectroCore Inlet and Outlet Particle Emission Rates.

CONCLUSIONS

The ElectroCore tests at E.C. Gaston showed the following.

- The ElectroCore has been scaled up by a factor of 12 from the original single-separator tests without a decrease in performance.

- The efficiency of the ElectroCore increases with increasing inlet particle concentration.

- The ElectroCore can achieve an outlet emission rate below 0.005 lb_m/million Btu

- The lowest emission rates are achieved when moderate, rather than maximum, voltages are applied to the separator central electrodes.

- The ElectroCore should be capable of achieving an emission rate of less than 0.03 lb_m/million Btu for power plants currently emitting at 0.4 lb_m/million Btu or less.

- There is potential for further improvements in performance by adjusting the separator electrode voltage to reflect changes in ElectroCore inlet loading.

The 6,000 acfm ElectroCore field prototype tested at E.C. Gaston Steam Plant will be the last ElectroCore prototype built. LSR and EPRI are currently looking for a site to build and test a full-scale ElectroCore system.

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